Performance Analysis of Three-layer LDM-MIMO System according to Pilot Patterns

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***Abstract*—A layered division multiplexing (LDM) system may give higher transmission efficiency compared to a single layer system. However, there still exists a demand to increase transmission capacity to provide various high-quality contents such as 8k-ultra high definition (UHD) TV. If the multiple-input multiple-output (MIMO) system and the three-layer LDM system are combined, the transmission capacity can be increased. When using a 2 by 2 MIMO system, the number of channels to be estimated increases from one to four. Therefore, the pilot pattern for estimating the channel must be different from the single-input single-output (SISO) system. In this paper, the performance of three-layer LDM-MIMO system is analyzed in single frequency network (SFN) according to two pilot patterns and two frequency interpolation methods.**

Keywords—layered division multiplexing; three-layer LDM-MIMO; MIMO pilot pattern; digital broadcasting;

I. INTRODUCTION

Most countries studying digital broadcasting technology are developing and standardizing next-generation broadcasting system to increase the transmission capacity [1]. Advanced television systems committee (ATSC) 3.0, the next-generation digital broadcasting system standard in United States, has a transmission capacity of more than 30% higher than the ATSC 1.0 [2]. Layered division multiplexing (LDM), a key technology of ATSC 3.0, is a frequency overlay technique that transmits multiple physical layer pipes (PLPs) on one radio frequency (RF) channel [3]. ATSC 3.0 uses a two-layer LDM system as a standard [4]. However, additional transmission capacity is still needed to provide large-capacity contents such as 8k-ultra high definition (UHD) TV and Internet of things (IoT). As a solution to this a three-layer LDM multiple-input multiple-output (MIMO) system has been considered.

When using the 2 by 2 MIMO system instead of a single-input single-output (SISO) system, the number of channels to be estimated increases from one to four [5]. Therefore, a pilot pattern must be different from SISO system. In this paper, Three-layer LDM-MIMO performance is analyzed in a single frequency network (SFN) channel using different two pilot patterns and two frequency interpolation methods. In a simulation, Walsh-Hadamard (WH) and null pilot (NP) patterns are used for a pilot pattern. Linear interpolation and discrete Fourier transform (DFT) interpolation are used for a frequency interpolation method.

II. THREE-LAYER LDM-MIMO SYSTEM

The MIMO system using two transmission antennas and two reception antennas can increase the transmission rate of three-layer LDM system compared to the SISO system. This MIMO system transmits the waveforms of the two antennas differently. One uses the longitudinal waveform and the other uses the transverse waveform. To transmit signals well in the MIMO system, the reception antennas must be fixed. This is because if the antenna is not fixed, attenuation occurs when receiving a

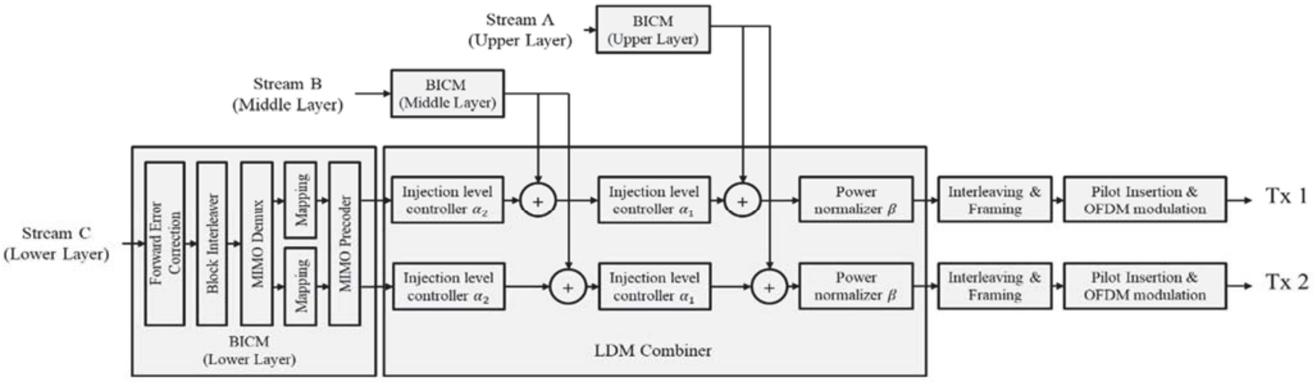

Fig. 1. Transmission block diagram of three-LDM MIMO system.

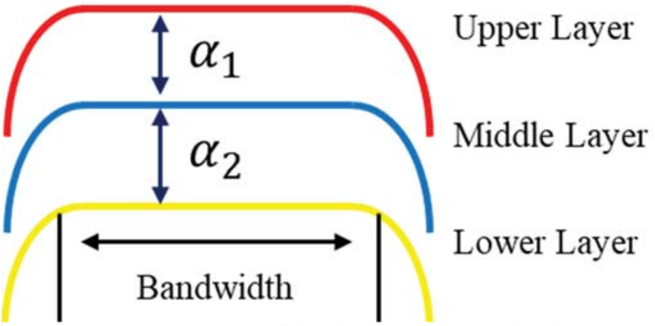

Fig. 2. Spectrum of three-layer LDM-MIMO signal

polarized waveform. Therefore, only the lower layer that targets fixed reception uses the MIMO system. Fig. 1 shows the transmission block diagram of the three-layer LDM-MIMO system. The two signals generated from the block diagram in Fig. 1 are transmitted respectively on two antennas. Fig. 2 shows the spectrum of three-layer LDM-MIMO signal. α_1 is the power difference between the upper layer and the middle layer. α_2 is the power difference between the middle layer and the lower layer.

The received signals of the three-layer LDM-MIMO system can be expressed as follows

$$\begin{aligned} Y_1 &= H_{1,1}X_1 + H_{1,2}X_2 + N_1 \\ Y_2 &= H_{2,1}X_1 + H_{2,2}X_2 + N_2. \end{aligned} \tag{1}$$

where N_1, N_2 are additive white Gaussian noise (AWGN) and X_1, X_2 are transmitted signals of each antenna. Y_1, Y_2 are received signals of each antenna and each $H_{i,j}$ is each channel.

III. MIMO CHANNEL ESTIMATION

When using the MIMO system, which is one of the techniques to increase the data rate in the limited bandwidth, it is necessary to estimate all the channels that occur over each path. For the 2 by 2 MIMO system used in this paper, four channel estimation is required. Therefore, the pilot pattern for estimating the channel must be different from the SISO system. There are two pilot patterns in the MIMO system [6]. One is Walsh-Hadamard pilot pattern, and the other is a null pilot pattern. These pilots can be used to estimate all four channels.

Fig. 3 shows the MIMO pilot pattern for WH pattern. WH pattern uses normal pilots and inverted pilots to estimate four channels. From the pilots at the normal pilot position of antenna2, following equations are derived.

$$\begin{aligned} \hat{H}_1^+ &= \frac{Y_1}{X_1} = \hat{H}_{1,1} + \hat{H}_{1,2}, \\ \hat{H}_2^+ &= \frac{Y_2}{X_1} = \hat{H}_{2,1} + \hat{H}_{2,2.} \end{aligned} \tag{2}$$

Since X_1 and X_2 are the same at normal pilot position, $\hat{H}_1^+$ and $\hat{H}_2^+$ can be obtained. From inverted pilots of two antennas, following equations are derived.

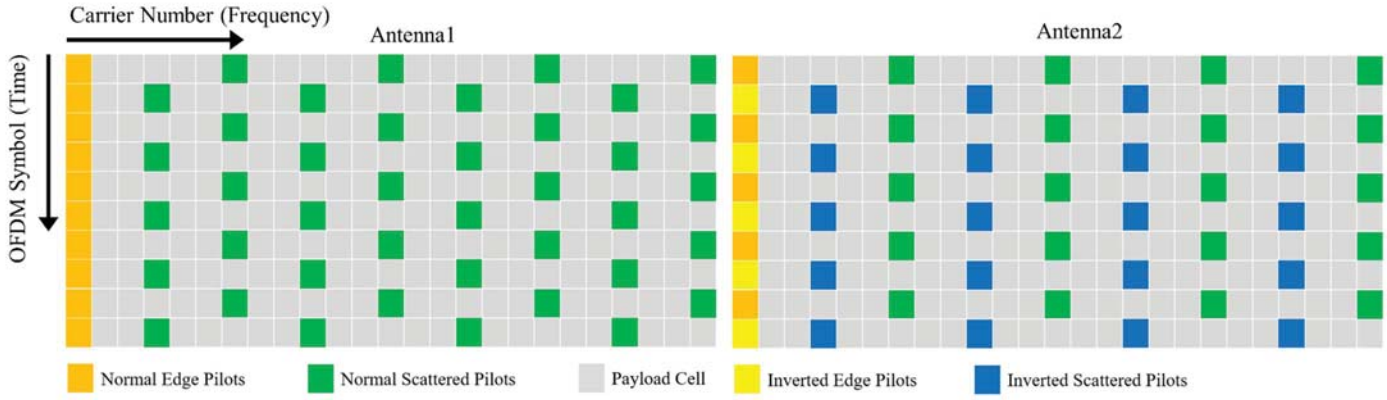

Fig. 3. Walsh-Hadamard pilot pattern of transmission antennas

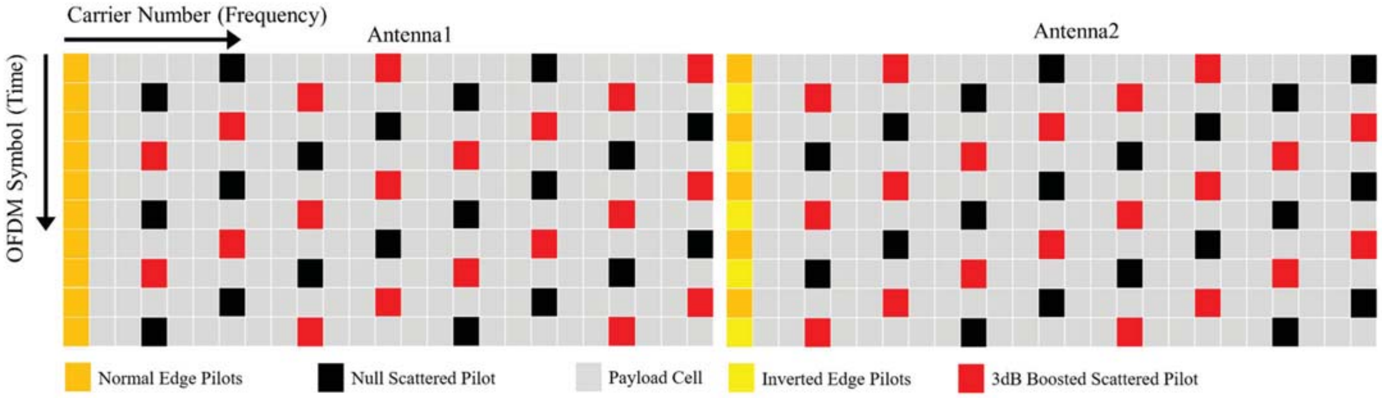

Fig. 4. Null pilot pattern of transmission antennas

$$\begin{aligned} \hat{H}_1^- &= \frac{Y_1}{X_1} = \hat{H}_{1,1} - \hat{H}_{1,2}, \\ \hat{H}_2^- &= \frac{Y_2}{X_1} = \hat{H}_{2,1} - \hat{H}_{2,2}. \end{aligned} \tag{3}$$

In the same way, since the value of X_1 and X_2 are same and the signs are opposite at inverted pilot position, $\hat{H}_1^-$ and $\hat{H}_2^-$ can be obtained. After interpolate $\hat{H}_i^{\pm}$, we can estimate all four channels.

$$\begin{aligned} \hat{H}_{1,1} &= \frac{\hat{H}_1^+ + \hat{H}_1^-}{2}, \hat{H}_{1,2} = \frac{\hat{H}_1^+ - \hat{H}_1^-}{2}, \\ \hat{H}_{2,1} &= \frac{\hat{H}_1^+ + \hat{H}_1^-}{2}, \hat{H}_{2,2} = \frac{\hat{H}_1^+ - \hat{H}_1^-}{2}. \end{aligned} \tag{4}$$

Fig. 4 shows the MIMO pilot pattern for NP pattern. NP pattern uses null pilots and 3dB boosted pilots to estimate four channels. From the 3dB boosted pilot of antenna1, following equations are derived.

$$\begin{aligned} \frac{Y_1}{X_1} &= \frac{\tilde{H}_{1,1}X_1}{X_1} + \frac{\tilde{H}_{1,2}X_2}{X_1} = \tilde{H}_{1,1}, \\ \frac{Y_2}{X_1} &= \frac{\tilde{H}_{2,1}X_1}{X_1} + \frac{\tilde{H}_{2,2}X_2}{X_1} = \tilde{H}_{2,1}. \end{aligned} \tag{5}$$

Since X_2 is null (zero) at 3dB boosted pilot position of antenna1, $H_{1,1}$ and $H_{2,1}$ can be obtained. From the 3dB boosted pilot of antenna2, following equations are derived.

$$\begin{aligned} \frac{Y_1}{X_1} &= \frac{\tilde{H}_{1,1}X_1}{X_1} + \frac{\tilde{H}_{1,2}X_2}{X_1} = \tilde{H}_{1,2} \\ \frac{Y_2}{X_1} &= \frac{\tilde{H}_{2,1}X_1}{X_1} + \frac{\tilde{H}_{2,2}X_2}{X_1} = \tilde{H}_{2,2}. \end{aligned} \tag{6}$$

In the same way, since X_1 is null (zero) at 3dB boosted pilot position of antenna2, $H_{1,2}$ and $H_{2,2}$ can be obtained. After pilot-based channel estimation, the frequency interpolation method uses linear interpolation and DFT interpolation.

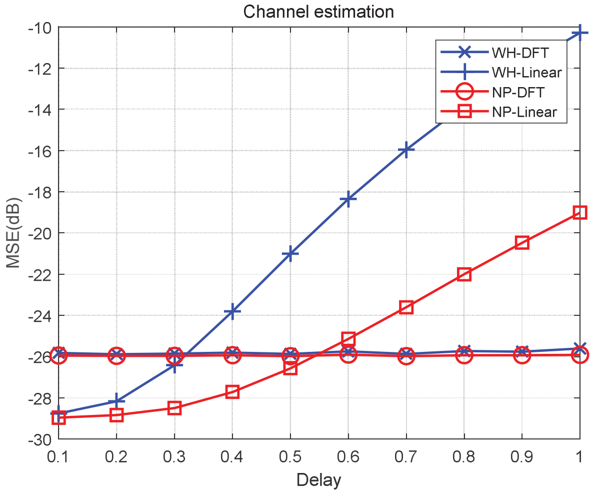

Fig. 5. Channel estimation error according to channel delay time.

TABLE 1 SIMULATION PARAMETERS

FFT Size	Guard Interval	Channel	α_1	α_2	XPD
8k	512 samples	2-tap SFN	2dB	2dB	18dB

IV. SIMULATION RESULT

Simulations were performed to compare the performance of two pilot patterns and two frequency interpolation methods of the three-layer LDM-MIMO system. The parameters used in the simulation are summarized in Table 1. The XPD is cross-polarization discrimination. The channel estimation error uses mean square error (MSE). And MSE is defined as follows:

$$MSE = E\left[\frac{1}{4}\sum_{i=1}^{2}\sum_{j=1}^{2}\left|\hat{H}_{i,j} - H_{i,j}\right|^2\right], \tag{7}$$

where $\hat{H}_{i,j}$ is estimated channel, $H_{i,j}$ is ideal channel.

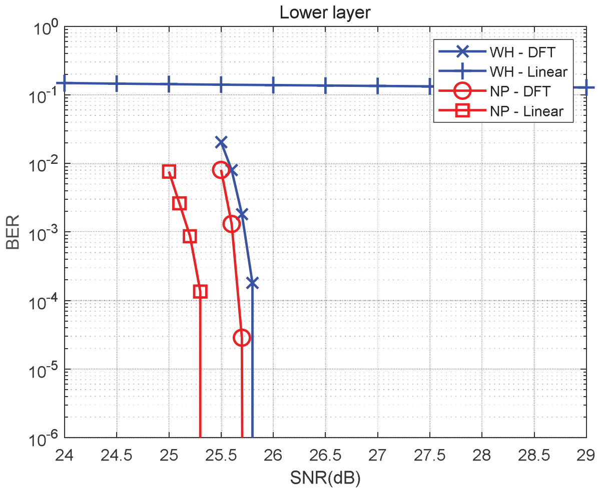

Fig. 6. BER performance when time delay is 0.5×GI

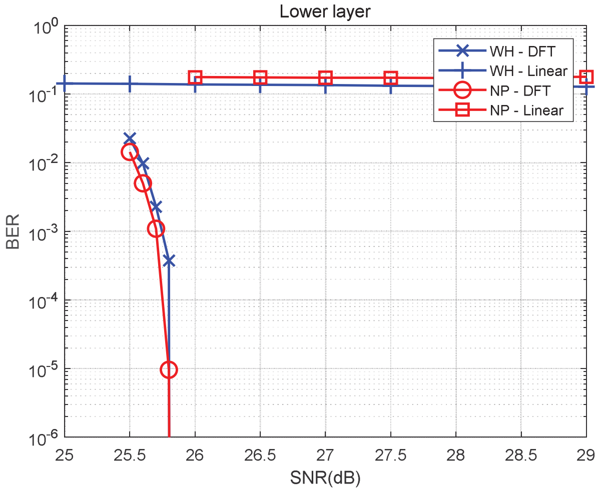

Fig. 7. BER performance when time delay is 0.9×GI

Fig. 5 shows the channel MSE according to the channel delay time. The channel delay used for the simulation is 0.1×GI to 1 × GI. In the linear interpolation method, the channel estimation performance is degraded as the channel delay time increases. However, the DFT interpolation methods is constant channel estimation even if the channel delay time increased. If the channel delay time is less than 0.55 × GI, the channel estimation performance is best when using NP-linear. If the time delay is greater than 0.55×GI, the DFT interpolation has better channel estimation performance than linear interpolation.

Fig. 6 shows bit error rate (BER) performance when the channel delay time is 0.5 × GI. and Fig. 7 shows BER performance when the channel delay time is 0.9×GI. When the channel delay time is 0.5×GI, the NP-linear shows 0.5dB better BER performance than NP-DFT. But WH-linear method cannot demodulate the signal. When the channel delay time is 0.9×GI, the DFT interpolations show best performance. But linear interpolations cannot demodulate the signal.

V. CONCLUSION

We analyzed the performance of a system combining MIMO system and three-layer LDM system according to pilot patterns and interpolation methods. Simulations were performed using WH, NP as a pilot pattern and linear, DFT as a frequency interpolation method in SFN channel. The performance of the three-layer LDM-MIMO system depends on the channel delay time. NP-linear shows better channel estimation performance than DFT interpolations at low channel delay time (less than 0.55×GI). DFT interpolations show better channel estimation performance than linear interpolations at high channel delay time (greater than 0.55×GI). When delay time is 0.5×GI, BER performance of NP-linear shows the best performance. But When delay time is 0.9×GI, NP-linear cannot work. Therefore, it is needed to consider the channel environments when designing an LDM MIMO system.

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